Rapid Drying of Ceramic and Efficient Food Processing with a Continuous Microwave Belt Furnace

S. Kasuriya* and D. Atong
National Metal and Materials Technology Center, 114 Thailand Science Park,
Klong Luang, Pathumthani, 12120, Thailand Tel: 0-2564-6500 Fax: 0-2564-6502 Email: supawank@mtec.or.th, duangdua@mtec.or.th

Abstract

Microwave heating has been widely applied in various applications. Generally, microwave technique is known as food preparation in house. More useful applications are drying of dielectric materials in rubber, ceramic, and food industries and sintering of advance composite materials. This work aimed at verifying the feasibility of drying various ceramic products and baking breads by applying microwave energy. The experiments were conducted using an 11.2 KW, 2.45GHz continuous microwave belt furnace. The effect of the irradiation time, microwave power, direction of transmitted wave, and sample size are studied. The results suggested that microwave heating system offered several advantages over conventional heating. Preliminary indication was that order of magnitude reduction in drying time was achieved. Furthermore, improvement in a product quality appeared to be possible because of the ability of microwave heating to minimize the amount of convective surface heating. Implementation of this drying process would greatly impact the manufacturing process in Thailand, reducing energy consumption, in-process inventory, factory space and labor requirements.

1. Introduction

The applications of drying process have been widely used in many types of industries such as food and ceramic industries. However, drying process by using energy from natural resources, such as solar energy, or conventional heating is not productive enough. In order to obtain high yields of production, microwave heating is one of the best choices to use in drying process. Microwave drying becomes popular to industrial and commercial applications because this technique has several advantages including shorter processing times, volumetric dissipation of energy throughout a product, high energy efficiency and improvement in product quality [1-10].

Microwave drying is fundamentally different from conventional drying in its heating mechanism. In conventional drying, the heat generated by heating elements is transferred to the sample surface by convection, and then transferred to the interior of the material by conduction. As heat goes from outside into a material, the moisture is expelled from the inside towards a surface where it evaporates. The rate of surface heat transfer is limited not only by the current convection dryer technology, but also by the need to minimize unwanted surface changes. The rate of conduction depends on the thermal properties of the body, which vary as moisture content decreases. This behavior tends to increase drying times and energy requirements. In contrast to conventional drying, heat generated by microwave energy depends on microwave absorption efficiency of materials including types and the dielectric properties of materials. During heated by microwave process, the water in the material absorbs microwaves throughout the entire mass causing molecular vibrations with respect to the oscillating electric field of microwaves and thus heating simultaneously throughout the material. In general, because of the heat losses at the surface, the interior part achieves higher temperature and dries first. Moisture inside is expelled to the surface with low pressure. [11-12].

The aim of ceramic drying process is to remove water from ceramic body as much as possible for preparing samples before firing at high temperature. However, there are many problems found in the conventional drying process because of the low thermal conductivity of material. The drying of ceramic materials is time consuming, non-uniform heating. Consequently, the finish products have a tendency to warp and produce cracking.

For food drying, the main purpose is to reduce the quantities of the water from food product in order to extend shelf-life much longer than the fresh food. In addition, the other benefit of drying process in food commodities is to try to cook them in an appropriate condition so that they would be cooked again by customers.

This paper describes the results of a test program performed to evaluate the technical feasibility of using microwave heating to dry food commodities including breads and chili powders, and ceramic material. The comparison of energy consumption and process capacity between microwave and conventional drying process was investigated.

2. Experimental

2.1 Microwave drying system

Microwave drying was performed in a microwave continuous belt drier (model MDBT 11.2kW) supported by Linn High Therm GmbH, Germany (Fig.1). The microwave frequency used was 2.45 GHz. The microwave power is generated by means of 14 compress air-cooled magnetrons of 800 watts each for a maximum of 11.2 kW. The magnetrons are arranged in a spiral around the longitudinal axis of the cylinder chamber to achieve a more uniform distribution of the field. This microwave drying system is appropriate to operate in a large scale of production. The drying can be controlled by the speed of conveyor belt, microwave power, and the location of magnetrons.

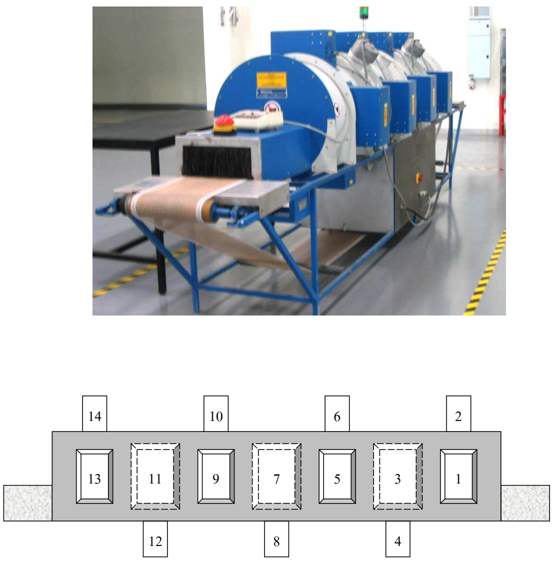


Fig. 1 A continuous microwave belt furnace and the location of magnetrons

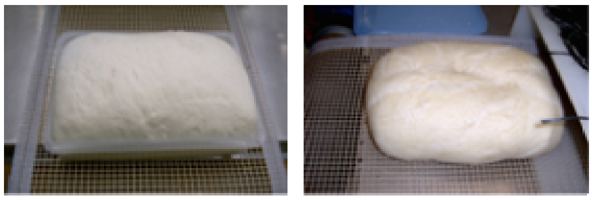
2.2 Description of testing

In this study, the food samples including baking breads and chili powder were provided by Globo Foods Co., Ltd. The tableware body selected for the drying test is the white porcelain clay with a chemical composition of 60.50 %SiO_2, 27.60%Al_2O_3, 3.65%K_2O, 1.14%Na_2O, 0.52%Fe_2O_3, 0.11%MgO, 0.09%CaO, 0.03%TiO_2, and 5.51% L.O.I. (L.O.I.; Loss on ignition). Drying time, microwave power, and sample size were studied. Weight change and surface temperature of sample were measured following each experiment. All temperatures were recorded with a hand-held optical thermometer. The moisture loss from a test sample was determined from weight change after drying. Sample quality and origin of sample failure were assessed visually with photographic documentation.

3. Results and Discussion

3.1 Baking of breads

All of the test dough were likely rectangular in shape with approximate dimensions of 10.5 cm in height, 24 cm in length and 18.5 cm in width and weighed about 1 kg (Fig. 2a). The initial moisture content of the dough was 38%. The dough was heated by electrical resistance oven for 1 hour. During the drying process, the temperature and moisture content is checked. The temperature of the bread must not exceed 90°C or it may be possible reductions to the quality of the baked bread. When the sample reaches final moisture content of about 28%, it is removed from the baking process. The process capacity and power consumption for baking bread using conventional drying oven are detailed in Table 1.



(a) (b)

Fig.2 Baking breads: (a) before and (b) after microwave drying

Table1 Baking bread using conventional drying oven

Conditions	Value
Initial temperature ($^{\circ}$C)	37
Final temperature ($^{\circ}$C)	90
Initial moisture content (%)	38
Final moisture content (%)	28
Process capacity/h	70kg
Power consumption/h	64KW

The interest in microwave drying was prompted by a good practical reason, viz., a necessity of obtaining high feed rates of dough for a continuous process. For microwave drying, doughs were removed from plastic bags and placed on the conveyor with a continuous flow rate of 40 sec/1kg. The radiation penetrates the doughs, heating the water until it diffuses to the surface of the baked bread. Hot air then evaporates the water and carries it away to atmosphere. Baked bread leaves the microwave cavity through another end of the conveyor belt. The bread dried in the continuous microwave belt drier yielded a water content of about 28%, similar to that from conventional drying. In most instances, the temperature of the bread rarely got over 80-90^{o}C. Example of the microwave - baked bread was presented in Fig.2b. The drying conditions and data obtained after microwave drying were shown in Table 2. With the duration time of 1 hour, the process capacity in microwave drying is observed to be 90kg/hour, which represents an improvement over the conventional drying. In addition, with the same quality of baked bread, energy consumption in microwave drying process decreases significantly from 64kW to 11.2kW compared to conventional drying. This preliminary result showed that microwave drying is more rapid and more highly energy efficient. These advantages of microwave energy have gained popularity for food industry not only for drying but also for cooking, thawing, sterilization, heating and re-heating.

Table2 Baking bread using a continuous microwave belt drier

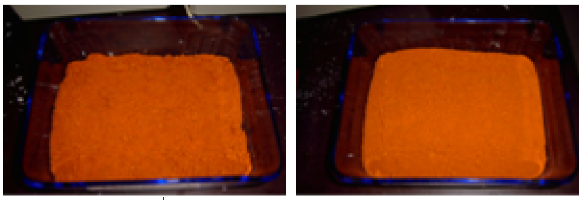
Conditions	Value
Initial temperature (^{O}C) Final temperature (^{O}C)	37 80-90
Initial moisture content (%) Final moisture content (%)	38 28
Process capacity/h	90kg
Power consumption/h	11.2KW

3.2 Drying of chili powder

Solar power is a convenient and cheap source of energy that can be easily applied to food drying. The conditions and result of drying chili powder using conventional method, solar energy, are shown in Table 3, while Table 4 shows the results for the microwave drying. The Initial temperature and moisture content of chili powder were in the range of 30-37 ^{O}C and 9-13 %, respectively. After exposing to the sun for 6 hour, the result demonstrated that temperature of sun dried chili powder would increase to 80 ^{O}C and moisture content would likely decrease to 3-5 %. This drying process had a maximum loading of 1500 kg.

Comparison drying tests of chili powders for microwave drying yield moisture content not different from moisture content based on solar drying. Drying of chili powders with moisture content of 9-13% by solar energy took approximately 6 hours. Microwaves need for the same only 1 hour. However, the energy consumption under microwave drying is about 5.6 kW for drying 5kg of chili powders. Because the system used was a demonstration unit and not adapted to food drying, the efficiency of energy input should be higher after a modification of the configuration, eg. longer microwave chambers and more magnetrons for a higher microwave power.

In this case, comparing between microwave and solar drying, the conventional method is more effective than microwave both energy consumption and a maximum loading of samples. However, microwave drying process would offer a benefit if chili could not be exposed to the sun due to unsuitable condition, eg. on a raining or high humidity day. To dry in the sun, hot, dry, breezy days are best. A minimum temperature of 30^{o}C is needed with higher temperature being better. Because the weather is uncontrollable, sun drying can be risky. Also the high humidity is a problem. Humidity below 60% is best for sun drying.



(a) (b)

Fig.3 Chili powder: (a) before and (b) after microwave drying

Table3 Drying chili powders using conventional drying oven

Conditions	Value
Initial temperature (^{O}C) Final temperature (^{O}C)	30-37 60-80
Initial moisture content (%) Final moisture content (%)	9-13 3-5
Process capacity/6h	1500kg
Power consumption/day	Expose to the sun

Table4 Drying chilli powders using microwave energy

Conditions	Value
Initial temperature (^{O}C) Final temperature (^{O}C)	30-37 80
Initial moisture content (%) Final moisture content (%)	9-13 3-5
Process capacity/h	5kg
Power consumption/h	5.6kW

3.3 Drying of ceramic products

Fig. 4 shows clay in the form of filter cake that prepared from filter pressing method. This wet and soft cake is the main raw material for the production of ceramic product through the slip casting or turning process. Microwave energy can be used to efficiently control the moisture content of this wet cake prior to shipment in order to reduce the production costs. At the same time, to obtain a form amenable to green forming of the ceramic, careful control of drying conditions is required in order to avoid cracking or exploding associated with uneven shrinkage of the dried filter cake bodies. Fig. 5 provides examples of failure and success experienced during the preliminary test. Note that the success obtained in the 8mm - filter cake sample is probably due to its greater surface – to – volume ratio and also low input microwave power used. When too high microwave power was applied, the sample exploded due to excessive internal pressure. Table 5 presents a series of trials performed to demonstrate the feasibility of drying without stress relief cracking.

Fig. 4 A filter cake before microwave drying

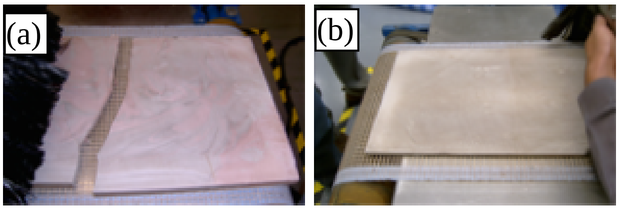


Fig. 5 A filter cake after microwave drying; (a) 15 mm. sample heated with 4 magnetrons (no. 2, 6, 10, 14) for 6 min, and (b) 8 mm sample heated with 2 magnetrons (no. 2 and 10) for 5 min.

Another microwave drying test was carried out on the turned tableware products. Generally, in the production process, the soft ceramic (filter cake) is turned on a turntable plaster mould to give its shape. The moulded products, still within the mould, are then dried typically with waste heat from the firing kiln for 15-45 min until a weight loss of 4-5% is obtained. The turned products are demoulded and further dried for about 1 hour where they are dried to the required weight loss of 9-10%. The preliminary results of microwave drying of tableware products are presented in Table 6. It is clear that demoulding times are drastically reduced to within 5 min, so that less floor space for demoulding is taken up and fewer moulds are used. The drying times of the demoulded products are also reduced from 1 hour to approximately 3 min in case of drying of the salad plate. In addition, as a result of the shorter drying times, the longer lifetime of the plaster moulds is expected to increase. After products were heated by two different methods, it was indicated that demolding of products by microwave drying obtained shorter processing time and more efficiency energy than conventional furnace. Moreover, the size of samples has an effect on processing time of demolding. Bigger size consumed time in demolding process more than small one.

Table 5 Results of microwave drying of 1 and 0.5cm - clay plate

Belt speed	No. of magnetron	Heating time (min)	Weight loss	
			1 cm	**0.5 cm**
High (0.04m/s) (1 min/cycle)	4	1	Explode	Explode
	3	6	Explode	16.40%
	2	9	Explode	16.38%
	1	16	15.12%	16.16%
Medium (0.02m/s) (2 min/cycle)	4	2	Explode	Explode
	3	6	Explode	Explode
	2	10	15.20%	16.18%
	1	16	14.40%	12.74%
Low (0.01m/s) (5 min/cycle)	4	5	Explode	Explode
	3	5	Explode	Explode
	2	5	Explode	Explode
	1	15	14.42%	15.46%

4. Conclusion

Application of microwave energy in drying and heating is not new. What seems to be new is the increased acceptance of non-cooking application of microwave energy by industry and the increased dissemination of such knowledge. This research demonstrated the technical feasibility of microwave technology applied in drying process of food and ceramic industrials using a continuous belt furnace. Utilization of microwaves accelerates the drying process, consequently reducing processing time, and production costs. Reduction in drying time translates directly into a lower in-process inventory of drying/baking pieces needed to satisfy production demands. Less factory space is a consequence of smaller in-process inventory. These reductions in processing time, inventory, and space requirements can be used to increase manufacturing capacity and reduce labor requirements. Moreover, microwave drying process is a clean technology that would be suitable to operate in many kinds of industries in Thailand,

Table 6 Results of microwave drying of turned tableware product

Product	Stage	Drying ondition		Results		
		No. magnetron	Time (min)	Temp (°C)	Wt.loss	Feature
Saucer	demoulding	7 (4 –top, 3-bottom)	15	80	10-15%	
Dinner plate	demoulding	7	5	45	4.22%	
		7	3	30	2.54%	
Salad plate	demoulding	4 (no.2,6,10,14)	5	42	1.62%	
	drying	4 (no.2,6,10,14)	3	32	7%	

especially export industry of the agricultural transformed products. Microwave drying can be an alternative choice for solar drying when the available drying condition is not suitable, eg. High humidity.

However, high temperature microwave processing can have a detrimental effect on product quality parameters, such as color and texture. Thus, careful control of process conditions is needed in order to avoid over heating or stress relief cracking. Laboratory testing is continuing in order to further optimize the microwave conditions and to extend them to the drying of other materials. Successful of this work is expected to lead to pilot plant testing followed by a full scale microwave dryer installation. Nevertheless, a paramount factor in the decision to adopt a microwave drying method is energy cost. No doubt future research to assess the relative costs for microwave drying versus other options is needed to provide an answer.

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